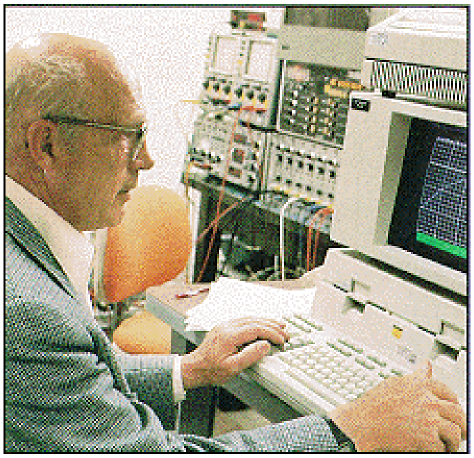
Bently's Corner



By Donald E. Bently
Chief Executive Officer

BENTLY ROTOR DYNAMICS RESEARCH CORPORATION

Rotor mode shape analysis for assessing machinery condition

Rotor mode shape analysis is proving to be an effective technique for assessing the condition of rotating machinery.

Bently Rotor Dynamics Research Corporation (BRDRC) is employing the technique to assist in diagnosing machine malfunctions. This method of analysis was used to investigate and confirm a shaft crack on a large turbine generator with a solidly coupled rotor and seven bearings. The technique is equally applicable to smaller two-bearing/single-shaft rotating machines.

The analysis method employed by BRDRC utilizes computer modeling of rotor mode shapes to characterize machine behavior. A rotor mode shape is the resultant deflected shape of a rotor at a specific rotative speed to an applied forcing function.

How mode shape analysis is performed

Rotor mode shape analysis is a particularly valuable technique for assessing machine condition because you can compare the theoretical machine behavior with how the machine is actually behaving. The analysis, performed by BRDRC, involves three steps: acquiring base data, mode shape generation, and analysis.

Two types of base data are required for rotor mode shape analysis:

1) Actual machine data: Observed 1X and 2X bow mode shapes acquired before and after the machine malfunction is suspected.

2) Theoretical machine data: Rotor design, bearing stiffness, and other dimensional information on the machine. ►

Bently Rotor Dynamics Research Corporation engineers use computer-simulated rotor mode shapes to gain additional information for assessing machine condition. The software program for rotor mode shape analysis is adapted from the Critical Speed program, developed by Dr. Edgar Gunter of the University of Virginia.

Mode shape generation

The theoretical machine data is entered into a computer to generate mode shapes for analysis. First, the rotor system is modeled to produce calculated undamped synchronous mode shapes based on the normal design conditions.

Next, the computer model is modified by simulating the malfunction condition, and a new set of rotor mode shapes is produced. These rotor mode shapes represent the computer predictions of machine behavior under normal and abnormal machine conditions.

It is important to note that the theoretical, computer-predicted rotor mode shapes may not exactly match the observed 1X and 2X bow mode shapes because a unit moment is assumed for each shaft section. In assuming the unit moment, the software program does not utilize any unbalance distribution along the shaft.

Rotor mode shape analysis

The computer-simulated rotor mode shapes provide additional information for comparison when assessing machine condition. The two sets of computer-predicted mode shapes—representing normal and abnormal machine condition—can be compared with the observed 1X and 2X mode shapes.

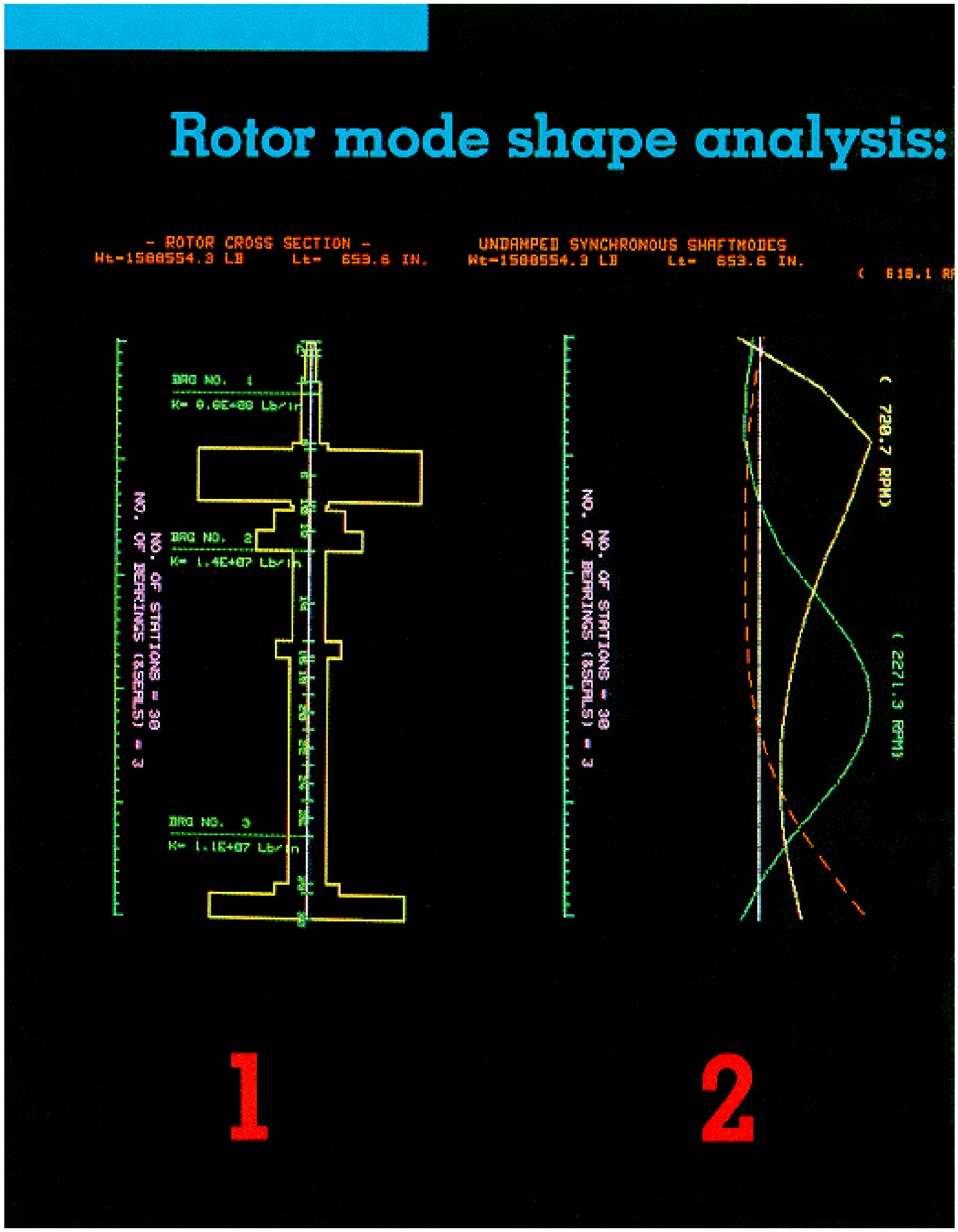
Changes or localized discontinuities between the rotor mode shapes can indicate that a potential problem exists and should be further investigated.

The software program utilized to perform computer modeling presents a graphic illustration of the sharp discontinuities in the rotor mode shapes. This is achieved by entirely eliminating computer curve smoothing so that minute rotor mode shape changes are readily apparent.

The software program is adapted from the Critical Speed program, developed by Dr. Edgar Gunter, Professor of Mechanical Engineering at the University of Virginia.

Identifying machine behavioral characteristics

Rotor mode shape analysis is particularly useful for investigating shaft cracks in large turbine generators. In addition to examining the effects of shaft cracks on rotor mode shapes, the results of rotor mode shape analysis can be used on turbine generators and other rotating machinery to identify:

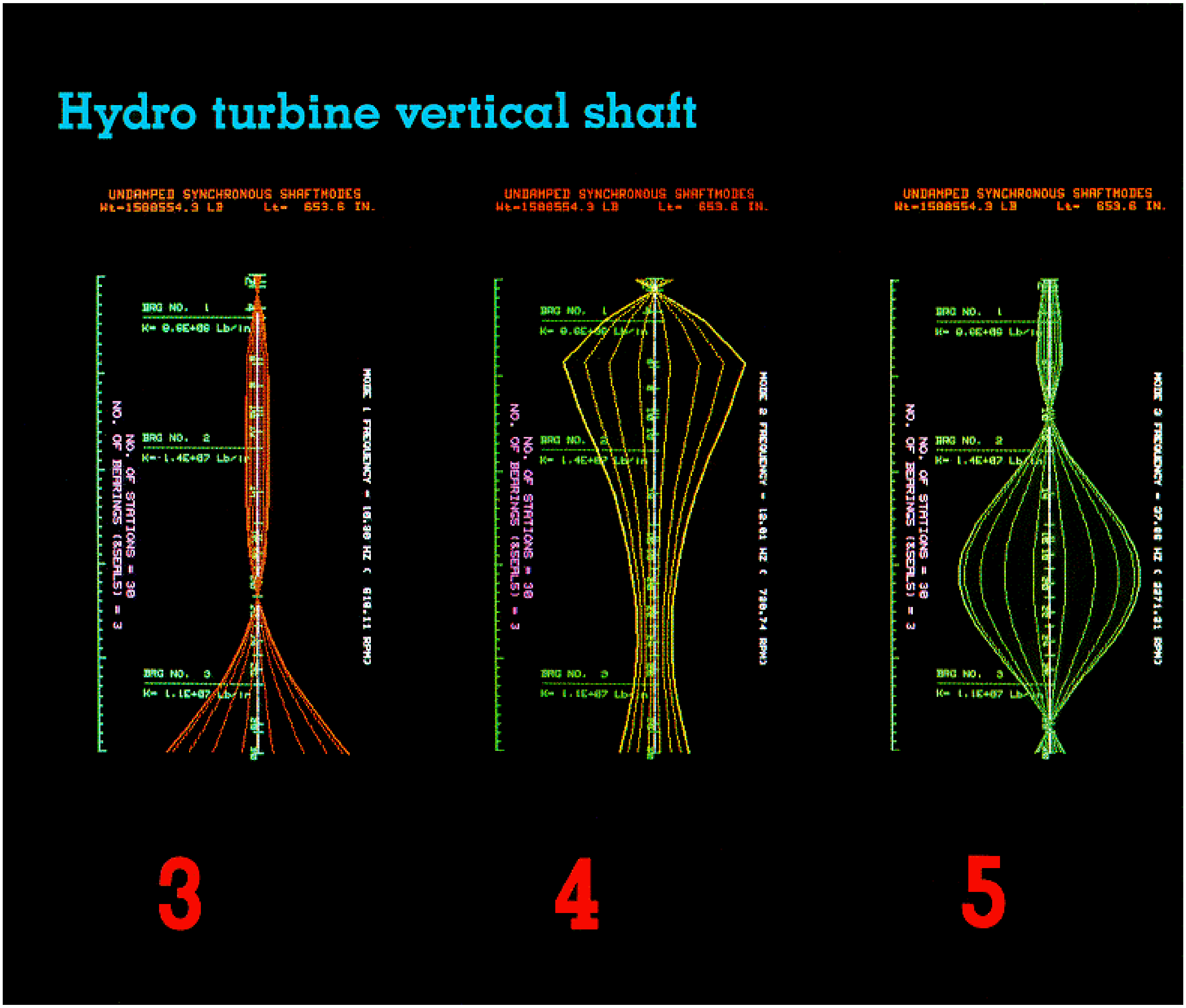


- ☐ Susceptibility to instability
- ☐ Rotor balance resonance frequencies as a function of shaft rotative speed
- ☐ Sequence of rotor mode shapes as speed changes
- ☐ Effects of excessive bearing clearances on rotor mode shapes
- ☐ Translational versus pivotal rotor mode shapes

Rotor mode shape analysis also can be used to determine:

- ☐ The most effective locations for balance weights
- ☐ Possible probe locations

On field balancing jobs, the direct and transfer responses obtained from Bently Nevada's ADRE® (Automated Diagnostics for Rotating Equipment) balancing package can be compared to the rotor mode shape diagrams to gain insight into the effects of various balance weight distributions on the rotor mode shape. When this technique is used, it must be remembered that these responses do not directly represent the rotor mode shape. Rather, they are the result of the modal response corresponding to the rotor mode shape.



Sample of computer displays of rotor mode shapes, on a hydro turbine vertical shaft:

1 Rotor cross section of machine; and

2 Composite display of three shaft modes; and undamped synchronous shaft mode shapes at

3 618 rpm,

4 720 rpm, and

5 2271 rpm.

Case study: Using rotor mode shape analysis to confirm a shaft crack

BRDRC has used rotor mode shape analysis to investigate and confirm a shaft crack on a turbine generator in power generation service.

Figure 1 shows the rotor mode shapes on the turbine generator under normal condition—without a shaft crack. Figure 2 shows the rotor mode shapes with a crack at Bearing #4.

Examination of the rotor mode shape on Figure 1 at the Intermediate Pressure/Low Pressure-Dual Flow Low Pressure (IP/LP-DFLP) Translation mode at 1562 rpm reveals a sharp peak in the Bearing #4 region. The peak characterizes this part of the rotor as a high-stress region.

As it turned out, the crack did indeed occur in the Bearing #4 area, as evidenced by the even sharper peak at the IP/LP-DFLP Translation mode at 1466 rpm (Figure 2).

Comparison of the resonant frequencies of IP/LP-DFLP Translation mode in Figures 1 and 2 shows that the resonant frequency has moved from 1562 rpm to 1466 rpm. The change is the result of the crack decreasing the shaft stiffness at this point.

For more information....

BRDRC has the capability of performing rotor mode shape analysis on various types of machines—from large turbine generators with several solidly coupled rotors and up to 15 bearings to smaller two-bearing/single-shaft rotating machines.

For more information on rotor mode shape analysis, write Ron Bosmans, Field Engineering Services Manager, or Wolf Campbell, Research and Development Engineer, Bently Nevada Corporation, P.O. Box 157, Minden, Nevada 89423, or call 702-782-3611.

For more information on shaft crack analysis, please contact Dr. Agnes Muszynska, Senior Research Scientist, or me at Bently Rotor Dynamics Research Corporation, P.O. Box 157, Minden, Nevada 89423, or call 702-782-3611. ■

Rotor mode shape analysis to detect shaft crack on a turbine generator

No Crack

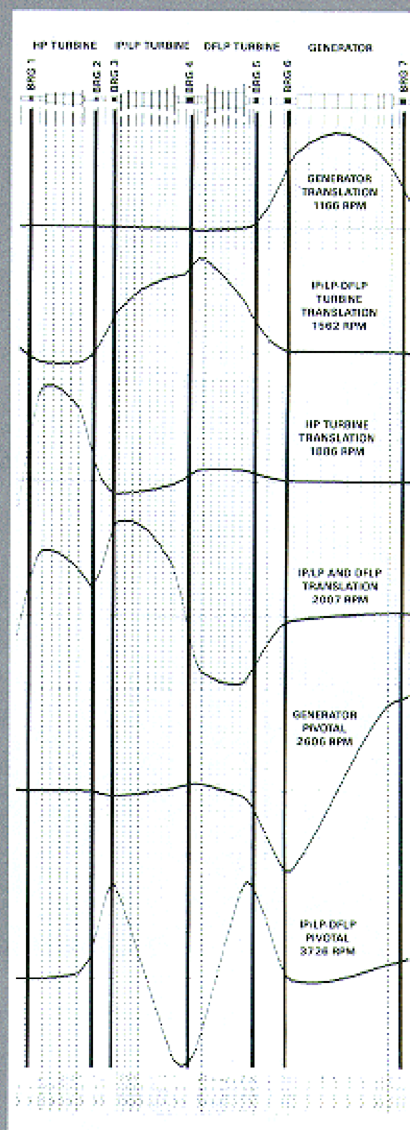


Figure 1: Rotor mode shapes on a turbine generator under normal condition—without a shaft crack

Shaft Crack

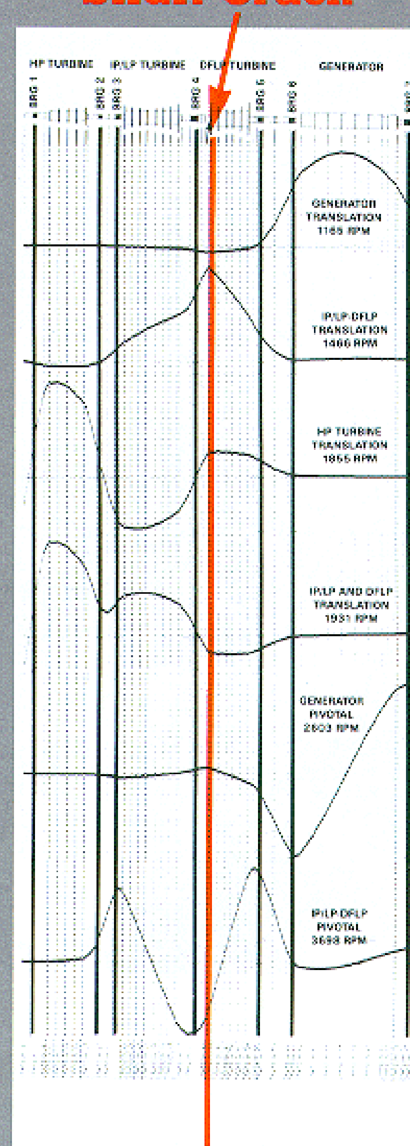


Figure 2: Rotor mode shapes on the same turbine generator with a shaft crack.